

13th COTA International Conference of Transportation Professionals (CICTP 2013)

## The demand analysis of bike-and-ride in rail transit stations based on revealed and stated preference survey

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### Abstract

Bike-and-ride users consist of existing and potential bike-and-ride members. This paper first conducts a revealed preference survey for metro travelers, and an additional stated preference survey for travelers who are transferred by bus or foot. Then it selects a residential area surrounded the metro station to implement a supplement survey. Through establishing binary logit model for three kinds of potential users, it finds the potential bicycle transfer possibility of the total metro station users and trips by different transferring modes. Finally, the paper presents a demand analysis of bike-and-ride in Nanjing Longmian Road Station.

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Selection and peer-review under responsibility of Chinese Overseas Transportation Association (COTA).

**Keywords:** Railway transit; bike-and-ride; disaggregated model; potential transfer demand

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### 1. Introduction

Due to its convenience, low energy consumption, high capacity, and efficiency attribute, the metro system is becoming one of the most promising public transport modes. It can efficiently relieve urban road congestions, promote sustainable development and improve a city's image and vitality. However, the main disadvantage of metro transport is that its coverage area is relatively small, and it cannot provide door-to-door services. Metro travelers often use another transport mode (like bus, car or bicycle) during access or egress trips to the metro stations.

During the process of metro system planning and construction, there are not enough transfer facilities around the railway stations because of the lack of relevant theory research. With the operation of metro system, the access and egress trips become the important restraining factor in the metro attractiveness. At the same time,

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some bicycles are parked improperly, which influence the order and efficiency of sidewalk and vehicle lanes. Thus, it is meaningful to research on the demand of bike-and-ride, and hence ascertain appropriate scale of bicycle transfer facilities.

Currently, the methods for bike-and-ride demand forecast include macroscopic forecast, regression analysis, expert decision-making, and disaggregate model. Zhang Dun et al. (1995) propose a macroscopic forecast method in case study of Beijing current situation of bicycle transfer. Based on the data of traffic zone trips, it gets bicycle transfer demand of one parking lot from the aspects of area control and construction. Suason Hendricks (1998) discusses the influence of parking space and fees for the variation of transfer demand. Since utility theory was introduced to transport planning by Domencich and McFadden (1975), a number of studies have been conducted on transport mode selection based on the disaggregate model, which mainly includes logit model and probit model. Some researchers develop some methods to improve these models (Black, 1995; Bhat, 2004). Recently, Patrick (2011) uses data mining and Brian (2012) uses stated preference survey to do some research on bike-and-ride. National researchers modify and improve each method on the basis of domestic situation and integration of abroad achievements. Mi Wenyong (2007) utilizes travel time and travel fees to describe the utility function, and establishes a logit model to calculate the possibility of bicycle transfer, including long distance trips by bicycle and bike-and-ride travelers.

The main advantage of disaggregate model is that it does not need large number of data for parameter modification. While current research stays on the theory level, and potential bike-and-ride travelers are not fully excavated. This paper makes fully excavation of potential bicycle transfer travelers, based on the revealed and stated preference survey. Potential bike-and-ride users consist of metro travelers who are transferred by bus or foot, and those who only use bicycles for long distance trips. It establishes binary logit model for three kinds of potential users and gets the potential transfer possibility of the total metro station and trips by different transferring modes. Later a case study of the Longmian road railway station of Nanjing is performed.

## **2. Data Collection**

Revealed preference survey (RP survey) asks the respondents to fill the questionnaire under the existing facility and policy. Stated preference survey (SP survey) offers several assumed scenarios for respondents to choose based on their own preference, which can get some indirectly measured or observed data. The number of assumed scenarios need be appropriate to both guarantee the quality of survey and reduce the answering time for respondents. So this paper uses homogeneous design (Wang Fang et al, 2005) and each respondent only selects their preference transport mode under six assumed scenarios.

This paper uses both revealed and stated preference survey. Revealed preference survey involves two aspects: trip property and personal property. Trip property consists of trip mode, trip purpose, access distance, walking time of considering using bicycle and so on. Personal property contains age, gender, income and family owned bicycle quantity and so on. Figure 1 depicts the variables used in this paper.

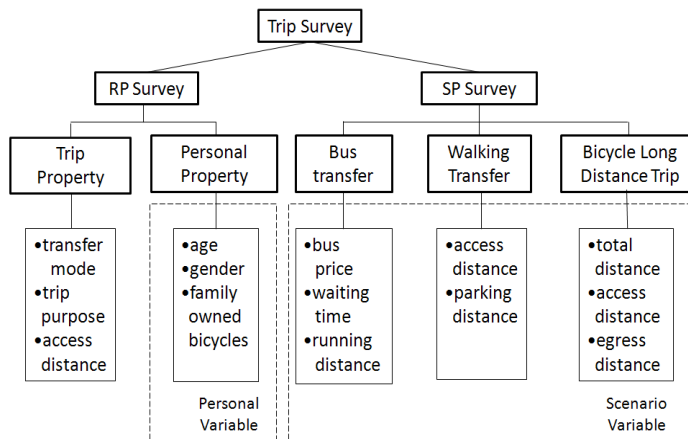


Fig. 1. Variables of trip survey

Survey is separated into two stages. The first stage is to randomly select respondents to do RP survey in a railway station. When these respondents choose walk, bus to transfer metro, they will continue to complete SP survey. By giving them six assumed scenarios, they choose their preference transfer mode, either previous transfer mode or bike-and-ride. In order to make these assumed scenarios accessible to respondents, these scenarios are designed into the pattern of diagram. The second stage is an accessory survey, which selects a residential area around the railway station. The distance between residential area and railway station should not exceed the upper radius limit of rational bicycle traffic zone (within 3.7 kilometers) (Brian C., Elaine B. & Orla T. M., 2012). Respondents are bicycle users. Those who only use bicycle for long distance trip are asked to do an additional SP survey. The design of SP survey assumed scenarios is shown from Figure 2 to Figure 4.

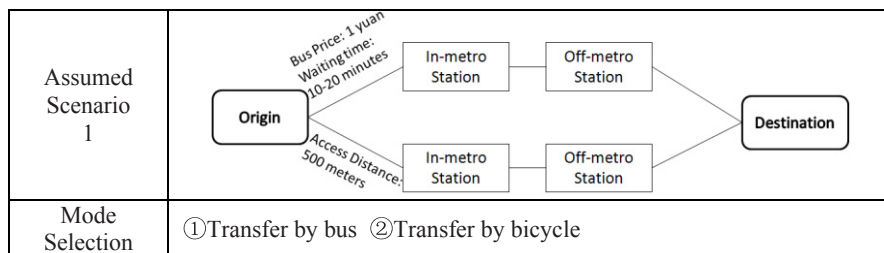


Fig. 2. SP survey design for metro trips transferred by bus

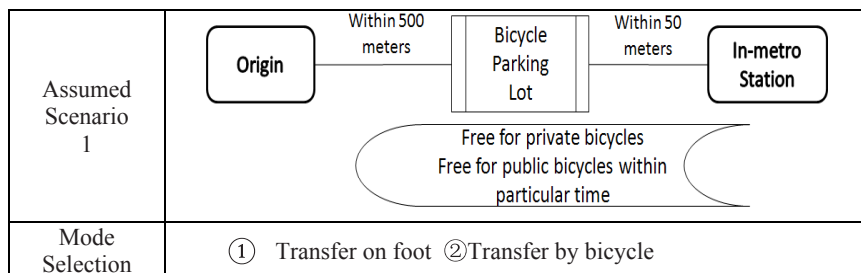


Fig. 3. SP survey design for metro trips transferred on foot

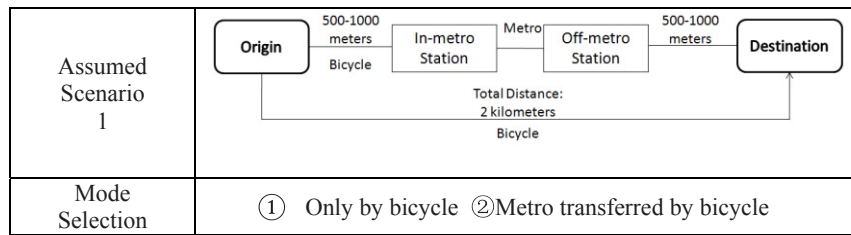


Fig. 4. SP survey design for trips only by bicycle

Variables of three kinds of potential bike-and-ride members are shown in table 1. By homogeneous design, these variables and personal variables aforementioned are made up six assumed scenarios. Responders select their transfer mode according to their own preference.

Table 1. Variables of three kinds of potential bike-and-ride users

Potential bike-and-ride users	Scenario variables	Values
Transfer by bus	bus price	1yuan, 2yuan, 3yuan
	bus waiting time	Within 10min, 10-20min, above 20min
	access distance	Within 500m, 500m-1km, 1-2km, 2-3km, 3-5km, Above 5km
Transfer on foot	access distance	Within 500m, 500m-1km, Above 1km
	bicycle parking distance	Within 50m, 50-100m, Above 100m
Only use bicycle	access distance	Within 500m, 500m-1km, 1-1.5km, 1.5-2km, 2-2.5km, 2.5-3km
	total distance	Within 2km, 2-4km, 4-6km, 6-8km, 8-10km, Above 10km
	egress distance	Within 500m, 500m-1km, Above 1km

### 3. Bike-and-Ride Demand Model

#### 3.1. Model Description

This paper establishes binary logit model for three kinds of potential bike-and-ride users in turn. Then it gets the potential transfer possibility of the total metro station and trips by different transferring modes. The flow chart of model parameter estimation and test is shown in figure 5.

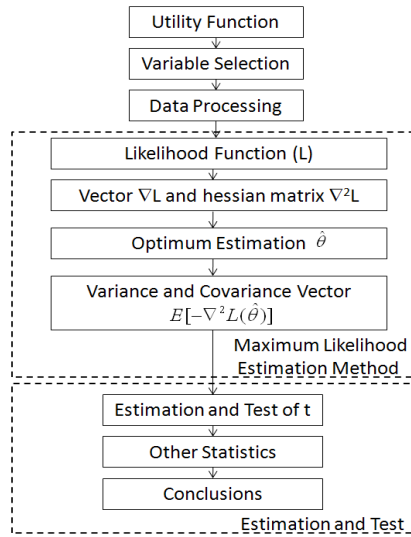


Fig. 5. Model parameter estimation and test

Utility factors are mainly divided into two parts, namely scenario variables in SP survey and three personal variables (age, income and bicycle quantity) in RP survey. The paper begins with a stepwise multiple regression analysis to find out proper utility factors from scenario variables and personal variables. Vectors  $\theta = [\theta_1, \dots, \theta_k]$  and  $X_{in} = [X_{in1}, \dots, X_{ink}]$  constitute the utility function  $V_n = f(\theta, X_{in})$ . Where  $\theta_k$  = unknown parameter of  $k^{\text{th}}$  selected variables,  $X_{ink}$  = value of the  $k^{\text{th}}$  selected variables of traveler  $n$  for the  $i^{\text{th}}$  trip mode and  $K$  = number of selected variables. As the most common pattern, the linear function is chosen as the utility function (as defined in equation 1).

$$V_n = \theta' X_n = \sum_{k=1}^K \theta_k (X_{1nk} - X_{2nk}) \quad (1)$$

The maximum likelihood estimation is used to calculate parameter  $\hat{\theta}$ , the approximate value of  $\theta$ . Here Newton-Raphson method (Guan Hongzhi, 2004) achieves the calculation of maximum likelihood estimation. The maximum likelihood function is expressed as:

$$\begin{aligned} L = \ln L^* &= \ln \left( \prod_{n=1}^N P_{1n}^{\delta_{1n}} \cdot P_{2n}^{\delta_{2n}} \right) = \sum_{n=1}^N (\delta_{1n} \ln P_{1n} + \delta_{2n} \ln P_{2n}) \\ &= \sum_{n=1}^N \left[ \delta_{1n} \ln \left( \frac{1}{1 + e^{-\theta'(X_{1n} - X_{2n})}} \right) + \delta_{2n} \ln \left( \frac{e^{-\theta'(X_{1n} - X_{2n})}}{1 + e^{-\theta'(X_{1n} - X_{2n})}} \right) \right] \end{aligned} \quad (2)$$

Where:  $P_{1n}$  = probability of selecting bicycle transfer mode,  $P_{2n}$  = probability of selecting previous mode,  $\delta_{1n} = 1, \delta_{2n} = 0$  means the respondent selects bicycle transfer mode and if the respondent still chooses the previous mode, then  $\delta_{1n} = 0, \delta_{2n} = 1$ ,  $N$  = sample size.

After calculating parameter  $\theta$ , it gets potential bicycle transfer possibility, defined as equation 3:

$$p_{1n} = 1 - p_{2n} = \frac{e^{-\theta'(X_{1n} - X_{2n})}}{1 + e^{-\theta'(X_{1n} - X_{2n})}} = \frac{\exp \left[ -\sum_{k=1}^K \theta_k \cdot (X_{1nk} - X_{2nk}) \right]}{1 + \exp \left[ -\sum_{k=1}^K \theta_k \cdot (X_{1nk} - X_{2nk}) \right]} \quad (3)$$

There are three indices to examine whether the model precision attains requirement.

(1) Test of  $t$ 

Test of  $t$  is  $t_k = \hat{\theta}_k / \sqrt{v_k}$ , where  $\hat{\theta}_k$  = the approximate value of  $\theta_k$ ,  $v_k$  = the  $k^{\text{th}}$  diagonal element of covariance

matrix. Under 5% significant level, if  $t_k > 1.96$ , the influence of variable  $X_{ink}$  on mode selecting probability is significant.

(2) Test of  $-2(L(0) - L(\hat{\theta}))$ 

Referring to chi square distribution table, value of degree of freedom  $K$  is  $\chi^2_{\alpha}$  ( $\alpha = 5\%$ ). If  $-2(L(0) - L(\hat{\theta})) > \chi^2_{\alpha}$ , there exists parameters significantly unequal to zero.

## (3) Test of hit rate

Comparing calculated values with actual output, hit rate is the ratio of sum of all  $\hat{\delta}_{in}$  (as defined in equation 1) to number of respondents. If hit rate exceeds 80%, model accuracy is performed well.

$$\hat{\delta}_{in} = \begin{cases} 1; \hat{P}_{in} \geq 50\% \\ 0; \hat{P}_{in} < 50\% \end{cases} \quad (4)$$

## 3.2. Ascertain Probability of Bike-and-Ride

Sample size of the first stage in a railway station is  $N_a$ , and sample size of the second stage is a residential area around the railway station is  $N_b$ . On the first stage, percentage of metro transfer by bicycle, bus, foot and other modes are  $P_{a1}, P_{a2}, P_{a3}, P_{a4}$  respectively ( $\sum_{i=1}^4 P_{ai} = 1$ ). During the accessory survey, percent of bike-and-ride and only bicycle are  $P_{b1}, P_{b2}$  ( $\sum_{i=1}^2 P_{bi} = 1$ ).

The average probability of three kinds of potential users is expressed as:

$$P_k = \frac{\sum_{i=1}^{N_k} p_i}{N_k} \quad (5)$$

Where:  $p_i$  = probability of potential bicycle transfer users,  $N_k$  = sample size of three kinds of potential users,  $N_1 = N_a * P_{a2}, N_2 = N_a * P_{a3}, N_3 = N_b * P_{b2}$  and  $k = 1, 2, 3$  represents metro transfer by bus, on foot and only bicycle users respectively.

Finally, the paper gets the potential bicycle transfer possibility of the total metro station, shown as follows:

$$P = P_{a1} + P_1 \cdot P_{a2} + P_2 \cdot P_{a3} + P_3 \cdot P_{a1} \cdot P_{b2} / P_{b1} \quad (6)$$

## 4. Case Study

In this section a case study of the Longmian road railway station of Nanjing is conducted based on the developed model. Sample size of the first stage is 258. Then Tianjingshan Apartment and Tianjingshan Chunxiu Guard are selected as the accessory residential area, sample size of the second stage is 46. Table 2 shows the percent of each transfer mode on the first stage.

Table 2. Nanjing Longmian Road Station survey sample

Survey	Sample Size	Trip Mode	Frequency	Percent
Railway Station	258	Transfer by Bicycle	27	11%
		Transfer by bus	76	29%
		Transfer on Foot	108	42%
		Transfer by Other Mode	47	18%
Accessory Survey	46	Transfer by Bicycle	9	21%
		Only by Bicycle	37	79%

The entire solving process of bus transfer is shown below. First SPSS statistics software is used to achieve stepwise multiple regressions trying to select proper variables as utility factors. Final selected variables from scenario variables and personal variables are shown on table 3.

Table 3. Selected variables in bus utility function

Selected Variables	Coefficient	Standard Error	t Stat	P-value
Bus Price	0.29091	0.02056	14.15181	0.00000
Bus Waiting Time	0.02062	0.00182	11.31436	0.00000
Access Distance	-0.00018	0.00001	-15.74074	0.00000
Family Income	-0.05609	0.02070	-2.71008	0.00702

Table 3 presents that age and family bicycle quantity is excluded because of little significant influence. Final selected variables are bus price, bus waiting time, access distance and family income. The next procedure is parameter confirmation of bus utility function, and results of modification are shown in table 4.

Table 4. Parameter confirmation of bus utility function

Trip Mode	Trip Property					Personal Property
	Inherent dummy	Variables				Variables
		Price	Waiting time	Access distance		Family income
Mode 1: transfer by bicycle	1	0	0	0	$X_{3n}$	$X_{1n}$
Mode 1: transfer by bus	0	1	$X_{1n}$	$X_{2n}$	0	0

After data processing, utility function of bus transfer is calculated based on Matlab program, which is shown below:

$$V_n = 1.4681 + 0.8425X_{1n} + 0.0640X_{2n} - 0.0016X_{3n} - 1.0004X_{4n} \quad (7)$$

Values of five  $t_k$  are 1.8001, 3.538, 2.587, -8.035 and -5.156 respectively. Four values satisfy the requirement of testing.  $L(0) = -274.486$ ,  $L(\hat{\theta}) = -136.919$  and  $-2(L(0) - L(\hat{\theta})) = 275.134 > \chi^2_{\alpha}$ , it means that there exists parameters significantly unequal to zero. Hit rate of bus transfer is 86.6% which presents that model precision is performed well. According to equation 5, the probability of potential bicycle transfer from bus transfer users is 17.9%.

In the same way, probability of two other potential bicycle transfer users is calculated, and finally the model gets potential bicycle transfer probability of the Longmian Road metro station. Results and testing indices are presented in table 5.

Table 5. Results and tests of Nanjing Longmian Road Station model

	Transfer by bus	Transfer on foot	Only by bicycle
Utility Function	$V_n = 1.4681 + 0.8425X_{1n} + 0.0640X_{2n} - 0.0016X_{3n} - 1.0004X_{4n}$	$V_n = -4.74086 + 0.00539X_{1n} - 0.00546X_{2n}$	$V_n = -4.4896 + 0.4597X_{1n} + 0.00053X_{2n} - 0.00095X_{3n}$
Value of $t_k$	1.8001, 3.538, 2.587, -8.035, -5.156, 4 values satisfy	-12.95, 13.23, 2.108, 2 values satisfy	-4.917, 6.358, 2.108, -1.715, 3 values satisfy
$L(0)$	-274.486	-461.636	-153.88
$L(\hat{\theta})$	-136.919	-257.659	-87.648
Hit Rate	86.6%	82.7%	79.3%
Model Precision	Good	Good	Good
Probability	$P_1 = 17.9\%$	$P_2 = 26.18\%$	$P_3 = 21.9\%$
Probability of potential bicycle transfer of Longmian Road metro station $P = 33.17\%$			

Table 5 depicts influence factors of three kinds of potential bicycle transfer users.

(1) Bus transfer users:

Values of  $t^k$  present that access distance is the most significant variable for bus transfer users. Its coefficient is negative, that means people tend to bike-and-ride. With the access distance increasing, the advantage of bicycle is gradually decreased. The following significant variables are bus price and bus waiting time. The higher the bus price or its waiting time, the more probability travelers will choose bicycle as their metro transfer mode. Coefficient of family income is negative which is in contrast with bus price. Bus price belongs to expense, travelers with higher income are less likely to consider bus price as an importance influence factor. They concern more about convenience. Those travelers with lower income may prefer to use bicycle as their transfer mode because of its relative lower expense.

(2) Walking transfer users:

Values of  $t^k$  also show that access distance is the most significant variable for travelers transferred on foot. Coefficient of access distance is positive means that when access distance is longer, transferring on foot becomes inconvenient. Travelers prefer to use bicycle as their metro transport mode. The influence of bicycle parking location is relatively lower. This variable will impact on the convenience and attractiveness of bicycle transfer.

(3) Travelers only by bicycle:

Values of  $t^k$  show that total distance is the most significant variable for travelers. Its coefficient is positive, which means metro is not suitable when total distance is short. When total distance gets longer, the advantage of metro is gradually obvious. The influence of access distance and egress distance is relatively lower. They will indirectly impact on the attractiveness of bike-and-ride.

## 5. Conclusions

Currently bike-and-ride is one of the major research directions of metro system. Bicycle as mode of access or egress to the metro system can efficiently solve the disadvantage of small coverage area of metro transport. On the basis of revealed and stated preference survey, this paper utilizes disaggregated model to fully excavate potential bicycle transfer travelers, and gets the potential transfer possibility of the total metro station and trips by different transferring modes. This study will provide useful information for government decision-making with



respect to bicycle transfer planning, and hence taking active action to optimize the bicycle transfer facility configuration and achieve greater efficiency of the metro transport system. Admittedly there are some limitations in our current research. For example, values of intervals of scenario variables are relatively rough. Besides there are some flaws in the design of tables and figures. These defects will be improved in the further research.

## Acknowledgements

This research is supported by the National Key Basic Research Program of China (No. 2012CB725400) and National Natural Science Foundation of China (No. 51178109).

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